System_Drivers_Stressors_Table (Draft 06/06/2014)

To inform monitoring practices and adaptive management strategies using best available scientific information (BASI), the tables below incorporate the following:

- **System Drivers** for each forest are identified as system drivers as exposures relative to trends. A few examples are natural succession, human disturbance, drought, temperature shifts, and sea level rise associated with climate change.
- **Stressors** for each resource are identified. This includes a summary of information from the scientific literature describing each resource's sensitivity to a particular system driver as well as important public concerns and values. Probability and risk of system driver may be included. Substantial uncertainty exists in trying to predict frequency and intensity of system driver.
- **Coarse and fine filter resources** are listed under the system drivers to which they are vulnerable, and their sensitivity is described, which is informed by the assessment findings. Coarse filter resources include systems (i.e. ecological, physical and social), while fine filter resources include species and assemblages.
- **Broad scale measures** are externally monitored indicators. Information is collected by sources such as National Oceanic and Atmospheric Agency (NOAA) or United States Geologic Survey (USGS), and this information is periodically examined to determine if trends exist, and if those trends are approaching trigger points (described below). If that trigger point is reached, management unit measures can be examined. For broad scale measures, we identify:
    - *Sources (S)* – a potential or established source of the monitoring that is external to the forest
    - *Frequency (F)* – the frequency with at which monitoring occurs, or the event initiating monitoring
    - *Scale (Sc)* – the geographic scale at which the monitoring occurs
    - *Information Quality (IQ)* – Includes measures of the accuracy, reliability, and relevance to the planning issue considered; if relevance is omitted, it is synonymous with scale for that example
    - *Alert (A)* – the condition that the monitoring measure or indicator passes (including measures of uncertainty) that may incite additional assessment, modifications to the monitoring, or need for change in the plan.
- **Management unit measures** are monitored at or near the forest, but still through an external source, such as an experimental forest if one exists. These measures may be incited by a trigger identified from broad scale monitoring, or done in conjunction with broad scale monitoring. If these measures reach the trigger point, then the resource is examined by means of the current forest monitoring. The same measures are identified for management unit measures and broad scale measures.

- **Current forest monitoring** ties these measures back to the forest. As the forests already engage in monitoring activities, we utilize the information gathered from these activities to inform whether or not the trigger has led to detectable changes within the forest. If negative changes have occurred and reached some critical threshold, then the need for change is assessed. If a need for change is identified, then possibilities for change are considered.

Possibilities for change are strategies to address the disturbances or negative shifts in forest health. These options are expected to create a forest ecosystem that is more resistant to future environmental threats. Given that these threats are often variable and unpredictable, forest managers should use both BASI and local knowledge of the forest to inform these decisions.

Boxes filled with red background indicate that a monitoring source has not yet been identified or confirmed with the partner.

Items with blue background indicate that a parameter and source have been identified, but not all items have been determined.

Hyperlinks are included if the resources and/or data are available online.

Climate Change

Coarse Filter Resources

System driver – Drought and Precipitation Changes

Focal Resource	Stressor	Broad Scale Measures; Indicators	Management Unit Measures; Indicators	Current Forest Monitoring	Possibilities for Change
Pine Forests	Radial growth in longleaf pine has been found to respond to either February precipitation or spring and summer precipitation (Bhuta et al., 2009). Longleaf pine (*Pinus palustris*) has greater drought tolerance than loblolly pine (*Pinus taeda*)	Precipitation **(S)** NOAA **(F)** Every 3-5 years (monthly data) **(IQ)** Accuracy – accurate within a scientifically	Precipitation **(S)** Santee Experimental Forest (SEF) **(F)** Every 3-5 years (monthly data) **(IQ)** Accuracy - observed	Acreage of forest type/tree species **(S)** GIS database **(F)** Annual **(IQ)** Currently unknown - based on accuracy and	Shift towards longleaf over loblolly, particularly following a drought disturbance event.

	and slash pine (*Pinus elliotii*), particularly on well-drained, sandy soils (Samuelson et al., 2012). The potential of drought to lead to more frequent or intense fires also favors longleaf over loblolly (Bhuta et al., 2009). Low soil moisture due to decreased precipitation is likely to be the most important factor limiting growth of loblolly pine, even if it responds favorably to increases in temperature and CO2. However, increases in precipitation could improve growing conditions (Wertin et al., 2012a).	appropriate degree of imprecision or error; reliability – real-time; relevance – near the forest **(Sc)** Sullivan's Island, SC, and/or Charleston International (nearest current temperature data) **(A)** Precipitation below **XX** mm per month Drought **(S)** NIDIS – Current and historical drought data **(F)** Annual **(IQ)** Current data: Accuracy – some data is provisional and could be inaccurate; reliability – updated daily to weekly; relevance – county level data Historical data: Accuracy – some data is provisional and could be inaccurate; reliability – no more than a 2-month consecutive gap in 40+ years of data; relevance – several stations near the forest **(Sc)** Berkeley and Charleston Counties **(A)** Significant increase in frequency and/or severity of droughts	and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest **(A)** Precipitation below **XX** mm per month Water Table **(S)** SEF **(F)** Every 3-5 years (monthly data) **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest **(A)** Soil moisture below **XX** on pine forest sites	reliability of GIS database **(Sc)** Forest **(A)** Decline in longleaf pine Forest and range health **(S)** Location and population trends of pests and diseases **(F)** Annual **(IQ)** Currently unknown-based on accuracy and reliability of forest monitoring **(Sc)** Forest **(A)** Increases in forest pests and diseases	
Recreation	Decreases in stream volume during the summer could negatively impact canoeing, rafting, and kayaking opportunities (Joyce et al., 2008).	Stream Flow **(S)** USGS Water Alerts **(F)** Annual (monthly low flow data) **(IQ)** Accuracy – provisional data may be inaccurate but is reviewed; reliability – real-time; relevance – on	Stream Flow **(S)** SEF **(F)** Annual (monthly low flow data) **(IQ)** Accuracy - observed and well documented; reliability – well documented including	Recreation **(S)** Usage of the park for water sports **(F)** Annual **(IQ)** Currently unknown-based on accuracy and reliability of forest monitoring	

		the forest **(Sc)** Watershed (8 digit HUC) **(A)** Significant decrease in flow, or increase in low flow days Drought **(S)** NIDIS – Current and historical drought data **(F)** Annual **(IQ)** Current data: Accuracy – some data is provisional and could be inaccurate; reliability – updated daily to weekly; relevance – county level data Historical data: Accuracy – some data is provisional and could be inaccurate; reliability – no more than a 2-month consecutive gap in 40+ years of data; relevance – several stations near the forest **(Sc)** Berkeley and Charleston Counties **(A)** Significant increase in frequency and/or severity of droughts	periods of missing data; relevance – on the forest **(Sc)** Watershed (12 digit HUC) **(A)** Significant decrease in flow, or increase in low flow days	**(Sc)** Forest **(A)** Significant decrease in usage of the park for water sports	

System driver – Temperature Shifts

Focal Resource	Stressor	Broad Scale Measures; Indicators	Management Unit Measures; Indicators	Current Forest Monitoring	Possibilities for Change
Pine Forests	Radial growth of loblolly pine (*Pinus taeda*) and longleaf pine (*Pinus palustris*) can be stressed under low winter temperatures, although these effects were seen at the	Temperature **(S)** NOAA **(F)** Annual (monthly and seasonal)	Temperature **(S)** SEF **(F)** Annual (monthly and seasonal)	Acreage of forest type/tree species **(S)** GIS database **(F)** Annual	Depending on temperature trends and effects on current species composition, consider

	northern latitudinal range margin rather than in South Carolina (Bhuta et al., 2009). Temperatures too far above or below the optimal will likely result in reduced growth of loblolly pine, such as the high temperatures in Gainesville, FL, or low temperatures in Coweeta, NC. A 1C change in mean annual temperature from the growth optimum can result in a 10% change in biomass growth (Nedlo, et al., 2009). Increased temperatures had a positive impact on loblolly pine growth at relatively warm and relatively cool sites in Georgia, with biomass accumulation increasing by 12% at the former and 30% at the latter (Wertin et al., 2012b).	**(IQ)** Accuracy – accurate within a scientifically appropriate degree of imprecision or error; reliability – real-time; relevance – near the forest **(Sc)** Sullivan's Island, SC, and/or Charleston International (nearest current temperature data) **(A)** Temperatures varying more than 1C from the growth optimum	**(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest **(A)** Temperatures varying more than 1C form the growth optimum	**(IQ)** Currently unknown - based on accuracy and reliability of GIS database **(Sc)** Forest **(A)** Decline in longleaf pine <u>Forest and range health</u> **(S)** Location and population trends of pests and diseases **(F)** Annual **(IQ)** Currently unknown- based on accuracy and reliability of forest monitoring **(Sc)** Forest **(A)** Increases in forest pests and diseases	planting species that thrive in the projected climate, if this action is concordant with other management objectives
Recreation	Too high of temperatures can negatively affect recreation in areas like FMNF, but fewer cold days can also encourage increases in warm-weather activities, and improve the attractiveness of South Carolina as a winter sun holiday destination (Scott et al., 2004; Joyce et al., 2008; Ramasamy & Swamy, 2012). Peak visitation season to national parks has shifted to earlier in the season with warming temperatures and advancing phenology. This trend is expected to continue (Buckley & Foushee, 2012).	<u>Temperature</u> **(S)** NOAA **(F)** Annual (monthly and seasonal) **(IQ)** Accuracy – accurate within a scientifically appropriate degree of imprecision or error; reliability – real-time; relevance – near the forest **(Sc)** Sullivan's Island, SC, and/or Charleston International (nearest current temperature data) **(A)** Significantly higher temperatures in winter or summer	<u>Temperature</u> **(S)** SEF **(F)** Annual (monthly and seasonal) **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest **(A)** Significantly higher temperatures in winter or summer	<u>Recreation</u> **(S)** Peak seasonal use, winter visitation, summer visitation **(F)** Annual **(IQ)** Currently unknown- based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant shift in timing or quantity of visitation	Promote recreation in shaded areas or cooler microclimates; prepare for peak visitation farther from the summer

System driver – Range Shifts

Focal Resource	Stressor	Broad Scale Measures; Indicators	Management Unit Measures; Indicators	Current Forest Monitoring	Possibilities for Change
Pine Forests	Climate change is expected to expand the range of longleaf and loblolly pine (Iverson & Prasad, 2001).	No monitoring needed, but sources would be Tree Atlas, FORWARN, Forecast, Landfire, GAP, Forest Health and Monitoring Annual Report	No monitoring needed	No monitoring needed	Collaborate with forests to where the species may soon migrate

System driver – Tropical Storms and Strong Winds

Focal Resource	Stressor	Broad Scale Measures; Indicators	Management Unit Measures; Indicators	Current Forest Monitoring	Possibilities for Change
Coastal Forests	Longleaf pine suffered the least damage from Hurricanes Katrina and Hugo, when compared to slash (*Pinus elliotii*) and loblolly pine (*Pinus taeda*) (Johnsen et al., 2009). Loblolly pine is susceptible to uprooting, due to its high "proportion of total carbon biomass above ground and in leaf tissue," particularly on "sandy soils with poorly anchored root systems," (McNulty, 2002). Historically, hurricane damage has occurred more in loblolly pine than in longleaf pine (*Pinus palustris*), baldcypress (*Taxodium distichum*), and live oak (*Quercus virginiana*), which are native to South Carolina's coastal plain. Mortality rates tend to be greater in stands with higher mean plot height (Johnsen et al., 2009). With highly tapered trunks, solid rooting, and open canopies, baldcypress is	High Winds **(S)** NOAA Extreme Winds **(F)** Annual (monthly extremes) **(IQ)** Accuracy – accurate within a scientifically appropriate degree of imprecision or error; reliability – real-time; relevance – on the forest **(Sc)** Carolinas coastal region **(A)** A significant increase in frequency or severity of high wind events	Windthrow **(S)** Santee Experimental Forest/ Baruch Institute **(F)** Annually, but only in years where major wind events have occurred **(IQ)** Unknown **(Sc)** Stand **(A)** Increasing instances of windthrow	Stand condition **(S)** Disturbances to pine forests from windthrow **(F)** Annual **(IQ)** Currently unknown- based on accuracy and reliability of forest monitoring **(Sc)** Stand **(A)** Significant increase in windthrow damage to pine forests	After major storm events, use of longleaf, live oak, and baldcypress when replanting storm-damaged stands if it proves more resilient than loblolly; after a wind-disturbance event, plant these species as well. When mean plot height is outstripping BAI, utilize management practices that promote outward rather than upward growth[1]

[1] In this study, despite the relationship between height and mortality, no relationship was found between height-to-diameter ratio and mortality. However, promoting outward rather than upward growth will reduce height growth and thus vulnerability to windthrow.

	among the least susceptible tree species to uprooting from hurricanes and suffer less hurricane damage than species such as loblolly pine (McNulty, 2002; Johnsen et al., 2009). Changes in stand structure and composition may alter water yields following hurricane damage (Jayakaran et al. 2014)				

System driver – Increasing Salinity

Focal Resource	**Stressor**	**Broad Scale Measures; Indicators**	**Management Scale Measures; Indicators**	**Current Forest Monitoring**	**Possibilities for Change**
Groundwater	Saltwater intrusion is initially expected to occur specifically when heavy rainfall coincides with high tide, then "areas lying within 0.33m of modern MHHW [mean higher high water] are especially vulnerable to the impacts of SLR by mid-century, whereas those lying between 0.66 and 1 m are vulnerable in the latter half of the century," (Rotzoll, 2012).	Specific Conductance **(S)** USGS WQ **(F)** Annual **(IQ)** Accuracy – provisional data may be inaccurate but is reviewed; reliability – real-time; relevance – on the forest **(Sc)** Carolinas coastal region **(A)** Significant increases in specific conductance	Salinity Levels **(S)** Baruch Institute **(F)** Every 3-5 years **(IQ)** **(Sc)** Forest (coast) **(A)** Salinity reaching areas within 0.33, of MHHW Specific Conductance **(S)** SEF and Baruch Institute **(F)** Every 3-5 years **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest (coast) **(A)** Significant increase in specific conductance		If salinity is increasing in groundwater, monitor health of salt intolerant plants within that range, and replant with salt tolerant species if mortality occurs.
Wetlands	With increasing salinity, freshwater wetlands composed of baldcypress (*Taxodium distichum*), water tupelo (*Nyssa aquatica* L.), swamp tupelo (*Nyssa*	Specific Conductance **(S)** USGS WQ **(F)** Annual **(IQ)** Accuracy – provisional	Salinity Levels **(S)** Baruch Institute **(F)** Every 3-5 years **(IQ)**		If salinity increases and mortality ensues, replant with baldcypress and any other salt tolerant species.

	biflora Walt.), ash (*Fraxinus* spp.), red maple (*Acer rubrum* L.), and/or oak (*Quercus* spp.) shifted towards only baldcypress with few swamp tupelo and red maple. Sites were also invaded by wax myrtle (*Morella cerifera* L.). However, salinities approaching 2.0 ppt and greater can decrease growth and increase mortality in baldcypress as well. Such sites may begin converting to marsh (Krauss et al., 2009).	data may be inaccurate but is reviewed; reliability – real-time; relevance – on the forest **(Sc)** Carolinas coastal region **(A)** Significant increase in specific conductance	**(Sc)** Forest (coastal wetlands) **(A)** Salinity approaching 2.0 ppt Specific Conductance **(S)** SEF or Baruch Institute **(F)** Every 3-5 years **(IQ)** (SEF) Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest (coast) **(A)** Significant increase in specific conductance		If conversion to marsh begins, choose management strategies that encourage high rates of accretion.

System driver – Sea Level Rise

Focal Resource	**Stressor**	**Broad Scale Measures; Indicators**	**Management Scale Measures; Indicators**	**Current Forest Monitoring**	**Possibilities for Change**
Salt Marshes	If accretion rates are insufficient to keep up with SLR, salt marsh areas in estuaries can be converted to low salinity marshes, then tidal flats, then open water (Gedan et al., 2011). Destruction of barrier islands will reduce protection from waves, causing marsh materials to flush out to sea (Daniels et al., 1993).	Sea Level Rise **(S)** NOAA Tides and Currents **(F)** Every 3-5 years **(IQ)** Accuracy – accurate within a scientifically appropriate degree of imprecision or error; reliability – real-time; relevance – on the forest **(Sc)** Springmaid Pier and Charleston gauges **(A)** Rise in sea level such that hydrology could be significantly altered in salt marshes	Water Levels **(S)** Baruch Institute/Cape Romain **(F)** Annually **(IQ)** **(Sc)** Salt marshes **(A)** Altered hydrology and/or water levels in salt marshes Accretion **(S)** Baruch Institute/Cape Romain **(F)** Annually **(IQ)** **(Sc)** Forest – coastal	Vegetation composition in salt marshes; ecosystem health in salt marshes	Restore natural hydrologic regimes. Plant species that promote accretion. Plant species that are flood and/or salt tolerant.

			(A) Accretion levels that are significantly outstripped by SLR		
Coastal Ecosystems – Barrier Islands	As SLR occurs, storm surges will reach farther inland and increase flood damage (Najjar et al., 2000; Day et al., 2008; Warner & Tissot, 2012). SLR, inundation, and lack of medium-grained sands to maintain the Cape Romain barrier islands will lead to fragmentation and destruction of the islands (Daniels et al., 1993; Chavez-Ramirez & Wehtje, 2011).	Sea Level Rise **(S)** NOAA Tides and Currents **(F)** Every 3-5 years **(IQ)** Accuracy – accurate within a scientifically appropriate degree of imprecision or error; reliability – real-time; relevance – on the forest **(Sc)** Springmaid Pier and Charleston gauges **(A)** Significant increase in projections of sea level rise High Winds **(S)** NOAA Extreme Winds **(F)** Annual (monthly extremes) **(IQ)** Accuracy – accurate within a scientifically appropriate degree of imprecision or error; reliability – real-time; relevance – on the forest **(Sc)** Carolinas coastal region **(A)** A significant increase in frequency or severity of high wind events	Sea Level Rise **(S)** Baruch Institute **(F)** Annually **(IQ)** **(Sc)** Forest **(A)** Significant increase in rate of sea level rise Coastal Erosion **(S)** Baruch Institute/Cape Romain **(F)** Every 3-5 years **(IQ)** **(Sc)** Forest **(A)** Significant levels of coastal erosion and inundation of barrier islands	Not currently in monitoring plan	As storm surges and resulting damages reach farther inland, restore with species that are more resistant to storm damages. As barrier islands disappear, shift to strategies that account for less protection for storm surges.
Tidally Influenced Riparian Zones	Reduced freshwater input from altered hydrologic systems reduces plant aboveground productivity, consequently reducing sediment trapping ability. Sediment-trapping, or accretion can help mitigate SLR and improve plant resilience to SLR (Day et al., 2008). SLR will increase the reach of tidally	Stream Water Levels **(S)** USGS Water Alerts **(F)** Every 3-5 years (compare with historical) **(IQ)** Accuracy – provisional data may be inaccurate but is reviewed; reliability – real-time; relevance – on the forest	Stream Water Levels **(S)** SEF **(F)** Annually **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest		If salinity and groundwater levels are rising, plant species along coasts that can tolerate higher salinity levels and high water tables, particularly if changes are observed in seedling survival and understory composition. If

	freshwater streams thereby altering the hydrology of the riparian wetland (Cwartacki 2013). The change in wetland hydrology may be expected to alter soil biogeochemical processes and forest productivity. Saltwater intrusion and elevated groundwater tables and consequent flooding can lead to forest retreat. Seedling survival will most likely decline before mature individuals die off. Understory composition can also change with forest retreat (Williams, et al., 1999)[2].	**(Sc)** Watershed (8 digit HUC) **(A)** Decreasing trend in water levels in fresh water streams Groundwater Levels **(S)** USGS **(F)** Every 3-5 years **(Sc)** Coastal Carolinas region **(IQ)** Accuracy – provisional data may be inaccurate but is reviewed; reliability – real-time; relevance – on the forest **(A)** Elevated coastal groundwater table Specific Conductance **(S)** USGS WQ **(F)** Annual **(IQ)** Accuracy – provisional data may be inaccurate but is reviewed; reliability – real-time; relevance – on the forest **(Sc)** Carolinas coastal region **(A)** Significant increase in specific conductance Coastal Forest Retreat **(S)** FIA **(F)** Every 5-7 years **(IQ)** Accuracy – designed to meet USFS sampling error standards for area, volume, growth, and removals; reliability –	**(Sc)** Forest **(A)** Decreasing trend in water levels in fresh water streams Groundwater Levels **(S)** SEF **(F)** Annually **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest **(A)** Increasing groundwater table Specific Conductance **(S)** SEF and Baruch Institute **(F)** Every 3-5 years **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest (coast) **(A)** Significant increase in specific conductance Coastal Forest Retreat **(S)** Santee Experimental Forest/Baruch Institute **(F)** Every 5-7 years **(IQ)** **(Sc)** Forest (coast) **(A)** Forest retreating XXm from 2014 levels		appropriate encourage vegetation that promotes accretion; when possible, restore natural hydrology

[2] This study was on the carbonate coast of West Florida and the variation in ecosystems should be considered.

		sufficient, but decreases as scale increases; relevance – nationwide but includes localized data **(Sc)** Coastal Carolinas region **(A)** Forest retreating XXm from 2014 levels			

System driver – Wildfire

Focal Resource	Stressor	Broad Scale Measures; Indicators	Management Scale Measures; Indicators	Current Forest Monitoring	Possibilities for Change
Forests	Wildfire risk is predicted to increase in the southeast, with temperature and drought as major contributors. Risks in the summer and autumn are greater, with the season potentially lengthening by two months as well (Heilman et al., 1998; Mitchener & Parker, 2005; Dale et al., 2009; Liu et al., 2012). Although increasing temperature is expected to increase burn area, this projection is limited by availability of fuels (Loehman et al., 2014).	<u>Temperature</u> **(S)** NOAA **(F)** Annual (monthly and seasonal data) **(IQ)** Accuracy – accurate within a scientifically appropriate degree of imprecision or error; reliability – real-time; relevance – near the forest **(Sc)** Coastal Carolinas region **(A)** Temperatures varying more than **XX**C from historical average <u>Precipitation</u> **(S)** NOAA **(F)** Annual (monthly precipitation) **(IQ)** Accuracy – accurate within a scientifically	<u>Temperature</u> **(S)** SEF **(F)** Annually (monthly and seasonal data) **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest **(A)** Temperatures varying more than **XX**C from historical average <u>Precipitation</u> **(S)** SEF **(F)** Annually (monthly precipitation) **(IQ)** Accuracy - observed and well documented; reliability – well	<u>Wildfire</u> **(S)** Acres burned in wildfire **(F)** Annual **(IQ)** Currently unknown- based on accuracy and reliability of forest monitoring **(Sc)** Forest **(A)** Significant increase in acres burned by Wildfire <u>Prescribed Fire</u> **(S)** Number of acres burned in prescribed fire **(F)** Annual **(IQ)** Currently unknown- based on accuracy and reliability of forest monitoring **(Sc)** Forest	Increase prescribed burning or removal of fuels.

		appropriate degree of imprecision or error; reliability – real-time; relevance – near the forest **(Sc)** Coastal Carolinas region **(A)** Precipitation below **XX** mm per month Drought **(S)** NIDIS – Current and historical drought data **(F)** Annual **(IQ)** Current data: Accuracy – some data is provisional and could be inaccurate; reliability – updated daily to weekly; relevance – county level data Historical data: Accuracy – some data is provisional and could be inaccurate; reliability – no more than a 2-month consecutive gap in 40+ years of data; relevance – several stations near the forest **(Sc)** Berkeley and Charleston Counties **(A)** Significant increase in frequency and/or severity of droughts	documented including periods of missing data; relevance – on the forest **(Sc)** Forest **(A)** Precipitation below **XX** mm per month	**(A)** Significant decrease in acres of prescribed burning	

System driver – Disturbance Events

Focal Resource	Stressor	Broad Scale Measures; Indicators	Management Scale Measures; Indicators	Current Forest Monitoring	Possibilities for Change
Recreation	Increasing disturbance events can cause the closing of recreation areas for either safety or conservation reasons, and also negatively impact scenery and other recreation values (Joyce et al., 2008; Ramasamy & Swamy, 2012).	Recreation Trends **(S)** National Visitor Use Monitoring Program **(F)** Annual **(IQ)** Accuracy – stratified random sample; relevance – national, regional, and forest **(Sc)** Regional; forest **(A)** Significant decrease in usage statistics High Winds **(S)** NOAA Extreme Winds **(F)** Annual (monthly extremes) **(IQ)** Accuracy – accurate within a scientifically appropriate degree of imprecision or error; reliability – real-time; relevance – on the forest **(Sc)** Carolinas coastal region **(A)** A significant increase in frequency or severity of high wind events Drought **(S)** NIDIS – Current and historical drought data **(F)** Annual **(IQ)** Current data: Accuracy – some data is provisional and could be inaccurate; reliability – updated daily to weekly; relevance – county level data Historical data: Accuracy –		Recreation **(S)** Quantity of visitors and closing of recreation sites **(F)** Annual **(IQ)** Currently unknown- based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant decrease in visitation or increase in closing of disturbance sites	If rebuilding damaged recreation sites, consider shifting to locations and building practices that are more resilient to disturbances

		some data is provisional and could be inaccurate; reliability – no more than a 2-month consecutive gap in 40+ years of data; relevance – several stations near the forest **(Sc)** Berkeley and Charleston Counties **(A)** Significant increase in frequency and/or severity of droughts			

Fine Filter

System driver – Increasing Salinity

Focal Resource	Stressor	Broad Scale Measures; Indicators	Management Scale Measures; Indicators	Current Forest Monitoring	Possibilities for Change
Baldcypress (*Taxodium distichum*)	Increasing salinity will favor baldcypress compared to other hardwood species in freshwater wetlands. However, salinities of 2.0 ppt may lead to photosynthetic dysfunction and reduce capacity for nutrient conservation, particularly of nitrogen. Decreased growth, decreased LAI, and increased mortality are likely at such salinity levels (Krauss et al., 2009).	Specific Conductance **(S)** USGS WQ **(F)** Annual **(IQ)** Accuracy – provisional data may be inaccurate but is reviewed; reliability – real-time; relevance – on the forest **(Sc)** Carolinas coastal region **(A)** Significant increases in specific conductance (tidally influenced riparian areas)	Salinity Levels **(S)** Baruch Institute **(F)** Annual **(IQ)** **(Sc)** Baldcypress stands on the margin of known saltwater systems **(A)** Salinity above 2.0 ppt Specific Conductance **(S)** SEF and Baruch Institute **(F)** Every 3-5 years **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest (coast) **(A)** Significant increase in specific conductance Growth (LAI; DBH) **(S)** Santee Experimental Forest/Baruch Institute; forest monitoring program **(F)** Annual **(IQ)** **(Sc)** Baldcypress stands on the margin of known	Not reported in most current Monitoring and Evaluation Report	If salinity increases and hardwoods begin dying, replace with baldcypress. Consider restoring natural hydrology to mitigate saltwater intrusion.

			saltwater systems **(A)** Growth rates slowing by **XX%**		
Non-Native Invasive Species (NNIS)	Increased salinity in floodplains can facilitate invasion of salt cedar (Tamarix spp.), (Rahel & Oden, 2008).	Specific Conductance **(S)** USGS WQ **(F)** Annual **(IQ)** Accuracy – provisional data may be inaccurate but is reviewed; reliability – real-time; relevance – on the forest **(Sc)** Carolinas coastal region (tidally influenced riparian areas) **(A)** Significant increases in specific conductance	Specific Conductance **(S)** SEF or Baruch Institute **(F)** Every 3-5 years **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest (coast) **(A)** Significant increase in specific conductance	NNIS **(S)** Invasive species abundance **(F)** Annual **(IQ)** Currently unknown-based on accuracy and reliability of forest **(Sc)** Forest (can focus on floodplains) **(A)** Significant increase in NNIS abundance	Increase efforts to control invasions

System driver – Drought, Flooding, and Precipitation Changes

Red Cockaded Woodpecker (RCW; *Picoides borealis Vieillot*)	Higher fall precipitation can lead to higher levels of infestation the next year, but drought also makes trees more vulnerable (Duehl et al., 2011; Lombardero et al., 2000b).	Precipitation **(S)** NOAA **(F)** Annual (monthly precipitation) **(IQ)** Accuracy – accurate within a scientifically appropriate degree of imprecision or error; reliability – real-time; relevance – near the forest **(Sc)** Forest **(A)** More than XX heavy rain events during fledgling growth periods Population Trends **(S)** North American Breeding Bird Survey **(F)** Every 3-5 years	Precipitation **(S)** SEF **(F)** Annually (monthly precipitation) **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest **(A)** More than XX heavy rain events during fledgling growth periods Fledgling survival rates **(S)** Santee Experimental Forest **(F)** Annual	RCW Populations **(S)** Number of active clusters; number of groups nesting **(F)** Annual **(IQ)** Currently unknown-based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant decrease in RCW active clusters or nesting groups	Take extra efforts to promote RCW populations, i.e. habitat improvement

		(IQ) Accuracy – not guaranteed; reliability – data released annually; relevance – regionally specific **(Sc)** Southeastern US **(A)** Significant decrease in populations or shift in range away from FMNF	**(Sc)** Forest **(A)** Fledgling survival rates declining significantly		
Southern Pine Beetle (SPB; *Dendroctonus frontalis*)	Higher fall precipitation can lead to higher levels of infestation the next year, but drought also makes trees more vulnerable (Duehl et al., 2011; Lombardero et al., 2000b).	Precipitation **(S)** NOAA **(F)** Annual (monthly precipitation) **(IQ)** Accuracy – accurate within a scientifically appropriate degree of imprecision or error; reliability – real-time; relevance – near the forest **(Sc)** Forest **(A)** Fall precipitation above XX mm Drought **(S)** NIDIS – Current and historical drought data **(F)** Annual **(IQ)** Current data: Accuracy – some data is provisional and could be inaccurate; reliability – updated daily to weekly; relevance – county level data Historical data: Accuracy – some data is provisional and could be inaccurate; reliability – no more than a 2-month consecutive gap in 40+ years of data; relevance – several stations near the forest	Precipitation **(S)** SEF **(F)** Annually (seasonal precipitation) **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest **(A)** Fall precipitation above XX mm	SPB Infestations **(S)** Location and population trends of SPB infestations **(F)** Annual **(IQ)** Currently unknown-based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant increase in infestations	Take extra precautions against SPB, i.e. shift away from planting host species, especially when replanting after beetle-kill

		(Sc) Berkeley and Charleston Counties **(A)** Significant increase in frequency and/or severity of droughts			
Northern Bobwhite	In Oklahoma, winter precipitation above 50 mm increased bobwhite counts, potentially through resulting increases in spring vegetation, seed abundance, and insect densities (Lusk et al., 2001).	No monitoring needed	No monitoring needed	No monitoring needed	
Amphibians	Precipitation shifts can alter physiological processes and lead to mortality. Small-bodied amphibians, and those adapted to moist forest floors are vulnerable to dessication, particularly in hot or dry environments. Shortened hydroperiods could hinder completion of metamorphosis before dessication occurs, or lead to smaller organisms at metamorphosis. Mole salamanders [genus Ambystoma] and eastern newts [Notophthalmus viridescens] are two species in the Coastal Plain of the southeastern US that require intermediate to long hydroperiods for reproduction, and could be threatened by climate change. Amphibians using ephemeral ponds time their reproduction according to precipitation (Corn, 2005; Richter_Boix et al., 2006; Todd & Winne, 2006; Rodenhouse et al., 2009; Blaustein et al., 2010)	<u>Precipitation</u> **(S)** NOAA **(F)** Annual (monthly precipitation) **(IQ)** Accuracy – accurate within a scientifically appropriate degree of imprecision or error; reliability – real-time; relevance – near the forest **(Sc)** Forest **(A)** Significant declines in precipitation trends <u>Drought</u> **(S)** NIDIS – Current and historical drought data **(F)** Annual **(IQ)** Current data: Accuracy – some data is provisional and could be inaccurate; reliability – updated daily to weekly; relevance – county level data Historical data: Accuracy – some data is provisional and could be inaccurate; reliability – no more than a 2-month consecutive gap in 40+ years of data; relevance – several	<u>Precipitation</u> **(S)** SEF **(F)** Annually (monthly precipitation) **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest **(A)** Significant declines in precipitation trends <u>Breeding Trends and Reproductive Success</u> **(S)** Santee Experimental Forest **(F)** Annually **(IQ)** **(Sc)** Forest **(A)** Significant decline in reproductive success or negative shift in breeding trends	<u>Amphibian Populations</u> **(S)** Location and population trends of key amphibian species **(F)** Annual **(IQ)** Currently unknown-based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant decrease in amphibian populations	Habitat restoration: ensure canopy cover over aquatic habitats, leave down wood for habitat both on land and in streams, promote appropriate microclimates

		stations near the forest **(Sc)** Berkeley and Charleston Counties **(A)** Significant increase in frequency and/or severity of droughts			
Mussels	Declining discharge can lead to mussel extirpation independently and due to fish extirpation (Spooner et al., 2011). Lower dissolved oxygen concentrations from drought can cause mussels to lower metabolic activity (Golladay et al., 2004). Floods can increase the dispersal of invasive zebra mussels, since their larvae are transported through streams (Havel et al., 2005).	Stream Flow **(S)** USGS Water Alerts **(F)** Annual (monthly low flow data) **(IQ)** Accuracy – provisional data may be inaccurate but is reviewed; reliability – real-time; relevance – on the forest **(Sc)** Watershed (8 digit HUC) **(A)** Significant decrease in flow, or increase in low flow days	Stream Flow **(S)** SEF **(F)** Annual (monthly low flow data) **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Watershed (12 digit HUC) **(A**) Significant decrease in flow, or increase in low flow days Dissolved Oxygen **(S)** SEF **(F)** Annual **(Sc)** Watershed (12 digit HUC) **(A)** Decrease in dissolved oxygen content below what is considered livable for these mussel populations	Mussel Populations **(S)** Location and population trends of mussels **(F)** Annual **(IQ)** Currently unknown-based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant decrease in mussel populations, and/or infestation of zebra mussels	Manage ecosystem (i.e. vegetation and nutrient inputs) to improve dissolved oxygen content; restore natural hydrology; control for zebra mussels
Fish	Decreased water levels can impact reproduction, respiration rates, metabolism, and can lead to extirpations and coextirpations (Sharma et al., 2007, Spooner et al., 2011).	Stream Flow **(S)** USGS Water Alerts **(F)** Every 3-5 years (low and high flows) **(IQ)** Accuracy – provisional data may be inaccurate but is reviewed; reliability – real-time; relevance – on the forest **(Sc)** Watershed (8 digit	Stream Flow **(S)** SEF **(F)** Every 3-5 years (low and high flows) **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest	Fish Populations **(S)** Location and population trends of key fish species **(F)** Annual **(IQ)** Currently unknown-based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant decrease	Restore natural hydrology

		HUC)	**(Sc)** Watershed (12 digit HUC) **(A)** Significant decrease in flows or increase in extreme low flow events	in fish populations	
Prairie Warbler (*Dendroica discolor*)	Predicted precipitation changes in the Southeast are expected to cause a decline in abundance of the Prairie Warbler (Matthews et al., 2012).	Precipitation **(S)** NOAA **(F)** Annual (monthly precipitation) **(IQ)** Accuracy – accurate within a scientifically appropriate degree of imprecision or error; reliability – real-time; relevance – near the forest **(Sc)** Forest **(A)** Significant declines in precipitation trends Population Trends **(S)** North American Breeding Bird Survey **(F)** Every 3-5 years **(IQ)** Accuracy – not guaranteed; reliability – data released annually; relevance – regionally specific **(Sc)** Southeastern US **(A)** Significant decrease in populations or shift in range away from FMNF	Precipitation **(S)** SEF **(F)** Annually (monthly precipitation) **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest **(A)** Significant declines in precipitation trends	Prairie Warbler Populations **(S)** Population of prairie warbler **(F)** Annual **(IQ)** Currently unknown-based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant decrease in prairie warbler populations	Habitat restoration

System driver – Temperature Shifts

Focal Resource	Stressor	Broad Scale Measures; Indicators	Management Unit Measures; Indicators	Current Forest Monitoring	Possibilities for Change

RCW	Increasing temperature causes RCW to lay eggs earlier, particularly older individuals, which can also lead to producing more fledglings. However, inbred RCW have not made this adjustment and their reproduction has suffered (Schiegg et al., 2002).	Temperature **(S)** NOAA **(F)** Every 3-5 years **(IQ)** Accuracy – accurate within a scientifically appropriate degree of imprecision or error; reliability – real-time; relevance – near the forest **(Sc)** Sullivan's Island, SC, and/or Charleston International (nearest current temperature data) **(Sc)** Regional **(A)** Increasing trend in temperature Population Trends **(S)** North American Breeding Bird Survey **(F)** Every 3-5 years **(IQ)** Accuracy – not guaranteed; reliability – data released annually; relevance – regionally specific **(Sc)** Southeastern US **(A)** Significant decrease in populations or shift in range away from FMNF	Temperature **(S)** SEF **(F)** Every 3-5 years **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest **(A)** Increasing trend in temperature Genetic Diversity of RCW **(S)** Santee Experimental Forest **(F)** Annually **(IQ)** **(Sc)** Forest **(A)** Low or decreasing genetic diversity Timing of Reproduction **(S)** Santee Experimental Forest **(F)** Annually **(IQ)** **(Sc)** Forest **(A)** Shift in timing of reproduction	RCW Populations **(S)** Number of active clusters; number of groups nesting **(F)** Annual **(IQ)** Currently unknown-based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant decrease in RCW active clusters or nesting groups	Actions to restore genetic diversity; habitat restoration
SPB	Cold winters and hot summers can reduce a SPB population from one year to the next, but warmer springs can increase the chance of outbreaks (Duehl et al., 2011; Gan, 2004).	Temperature **(S)** NOAA **(F)** Every 3-5 years (seasonal temperature) **(IQ)** Accuracy – accurate within a scientifically appropriate degree of imprecision or error; reliability – real-time; relevance – near the forest **(Sc)** Regional **(A)** Spring temperatures	Seasonal Temperature **(S)** SEF **(F)** Every 3-5 years (seasonal temperature) **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest **(A)** Spring temperatures	SPB Infestations **(S)** Location and population trends of SPB infestations **(F)** Annual **(IQ)** Currently unknown-based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant increase in infestations	Take extra precautions against SPB, i.e. shift away from planting host species, especially when replanting after beetle-kill

		above XXC	above XXC		
Amphibians	Temperature shifts can result in alteration of physiological functions, which can lead to changes in reproduction, immune function, feeding, dispersal, and ultimately mortality. Warmer water can have lower dissolved oxygen concentrations, which can negatively affect developing embryos and larvae, and delay development and hatching. Breeding can occur earlier with increasing temperatures and after warm winters, particularly with amphibians who use permanent ponds for breeding because they time breeding according to temperature (Blaustein et al., 2001; Care & Alexander, 2003; Richter_Boix et al., 2006; Rodenhouse et al., 2009; Blaustein et al., 2010).	<u>Temperature</u> **(S)** NOAA **(F)** Every 3-5 years **(Sc)** Regional **(A)** Shifts in temperature trends	<u>Temperature</u> **(S)** Santee Experimental Forest **(F)** Every 3-5 years **(Sc)** Forest **(A)** Shifts in temperature trends <u>Breeding Trends and Reproductive Success</u> **(S)** Santee Experimental Forest **(F)** Annually **(Sc)** Forest **(A)** Significant decline in reproductive success or negative shift in breeding trends	<u>Amphibian Populations</u> **(S)** Location and population trends of key amphibian species **(F)** Annual **(IQ)** Currently unknown- based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant decrease in amphibian populations	Habitat restoration: ensure canopy cover over aquatic habitats, leave down wood for habitat both on land and in streams, promote appropriate microclimates
Mussels	Increased water temperature has been tied to alterations in survival, heart rate, and growth of juvenile mussels. While warmer temperatures can lead to higher growth rates in juveniles, critical temperature thresholds can reduce growth (Ganser et al., 2013). Increasing temperatures, which are exacerbated when human activities and/or drought cause low flows, can lead to mussel mortality and shifts towards more thermally tolerant species. Mortality events can lead to "large nutrient pulses (Vaughn et al., 2008), algal blooms, lowered dissolved oxygen levels, and thus further mussel mortality," (Galbraity et al., 2010). In Oklahoma, community structure and ecosystem services were altered at 35C, and mortality in some thermally sensitive species was observed at 37-38C (Spooner & Vaughn, 2008).	<u>Temperature</u> **(S)** NOAA **(F)** Every 3-5 years **(Sc)** Regional **(A)** Significant increase in temperature trends <u>Water Temperature</u> **(S)** USGS **(F)** Every 3-5 years (high temperatures) **(Sc)** Carolinas coastal region **(A)** Significant increase in water temperatures	<u>Temperature</u> **(S)** Santee Experimental Forest **(F)** Annual **(Sc)** Forest **(A)** Significant increase in temperature trends <u>Water Temperature</u> **(S)** Santee Experimental Forest **(F)** Annual (high temperatures) **(Sc)** Forest **(A)** Significant increase in water temperature	<u>Mussel Populations</u> **(S)** Diversity and population trends of mussels **(F)** Annual **(IQ)** Currently unknown- based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant decrease in mussel populations and/or diversity	Where possible, increase shade in riparian areas to moderate temperature increases
Fish	Increased temperature can affect fish "thermal tolerance, growth, metabolism,	<u>Temperature</u> **(S)** NOAA	<u>Temperature</u> **(S)** Santee Experimental	<u>Fish Populations</u> **(S)** Location and	Where possible, increase shade in riparian areas to

	food consumption, reproductive success, and the abiliy to maintain internal homeostasis (Ficke et al., 2007). Atrazine, a herbicide, becomes more toxic to catfish, and potentially to other aquatic organisms, under increased temperature and decreased dissolved oxygen, (Noyes e al., 2009).	**(F)** Every 3-5 years **(Sc)** Regional **(A)** Significant increase in temperature trends <u>Water Temperature</u> **(S)** USGS **(F)** Every 3-5 years (high temperatures) **(Sc)** Carolinas coastal region **(A)** Significant increase in water temperatures	Forest **(F)** Annual **(Sc)** Forest **(A)** Significant increase in temperature trends <u>Water Temperature</u> **(S)** Santee Experimental Forest **(F)** Annual (high temperatures) **(Sc)** Forest **(A)** Significant increase in water temperature	population trends of key fish species **(F)** Annual **(IQ)** Currently unknown-based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant decrease in fish populations	moderate temperature increases
NNIS	Under increased temperature regimes, certain invasive species may experience range expansion into regions where they were previously cold limited (Morrison et al., 2005). Increases in food abundance with warming temperatures in aquatic habitats will provide more opportunities for invasive species to propagate (Rahel et al., 2008). The Cuban Treefrog (Osteopilus septentrionalis)could expand its range into FMNF within the next 80 years (Rudder & Weinsheimer, 2009). The FMNF is within the predicted suitable range for Burmese Python (Python molurus) for 2100 under multiple climate scenarios (Rodda et al., 2009). Chinese Tallow (Triadica sebifera) is expected to spread northward into FMNF's range under increased temperature scenarios (Pattison & Mack, 2009).	<u>Temperature</u> **(S)** NOAA **(F)** Every 3-5 years **(Sc)** Regional **(A)** Significant increase in temperature trends <u>Invasive Species Range Shifts</u> **(S)** EDD Maps; Potential Veg; GAP; Landfire **(F)** Every 3-5 years **(Sc)** Southeastern United States **(A)** Significant shift in invasive species predicted or known range towards FMNF	<u>Temperature</u> **(S)** Santee Experimental Forest **(F)** Every 3-5 years **(Sc)** Forest **(A)** Significant increase in temperature trends	<u>NNIS</u> **(S)** Invasive species range and abundance **(F)** Annual **(IQ)** Currently unknown-based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant increase in NNIS abundance and/or range	Take extra measures to control invasive species

System driver – Range Shifts

Focal	**Stressor**	**Broad Scale Measures;**	**Management Unit**	**Current Forest**	**Possibilities for Change**

Resource		Indicators	Measures; Indicators	Monitoring	
SPB	Climate change is expected to expand the range of SPB into mid-Atlantic states (Joyce, et al., 2008; Weed et al., 2013; Williams & Liebhold, 2002).	No monitoring needed, but sources would be: Tree Atlas, FORWARN, Forecast, Landfire, GAP, Forest Health and Monitoring Annual Report	No monitoring needed	No monitoring needed	Collaborate with forests to where the species may soon migrate
Bachman's Sparrow (*Aimophila aestivalis*)	The range of Bachman's Sparrow is predicted to shift southward by 176.25 ± 83.49 km over a 26-year period (Hitch & Leberg, 2007).	Population Trends **(S)** North American Breeding Bird Survey **(F)** Every 3-5 years **(IQ)** Accuracy – not guaranteed; reliability – data released annually; relevance – regionally specific **(Sc)** Southeastern US **(A)** Significant decrease in populations or shift in range away from FMNF		Bachman's Sparrow Populations **(S)** Population trends of Bachman's Sparrow **(F)** Annual **(IQ)** Currently unknown- based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant decrease in Bachman's Sparrow populations	Restore habitat
Swainson's Warbler (*Limnothlypis swainsonii*)	The range of Swainson's Warbler is predicted to shift northward by 79.92 ± 68.65 km over a 26-year period (Hitch & Leberg, 2007).	Population Trends **(S)** North American Breeding Bird Survey **(F)** Every 3-5 years **(IQ)** Accuracy – not guaranteed; reliability – data released annually; relevance – regionally specific **(Sc)** Southeastern US **(A)** Significant decrease in populations or shift in range away from FMNF		Swainson's Warbler Populations **(S)** Population trends of Bachman's Sparrow **(F)** Annual **(IQ)** Currently unknown- based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant decrease in Bachman's Sparrow populations	Restore habitat
Prarie Warbler (*Dendroica discolor*)	The range of Prairie Warbler is predicted to shift northward by 16.70 ± 33.40 km over a 26-year period (Hitch & Leberg, 2007).	Population Trends **(S)** North American Breeding Bird Survey **(F)** Every 3-5 years **(IQ)** Accuracy – not guaranteed; reliability – data released annually; relevance – regionally specific		Prairie Warbler Populations **(S)** Population trends of Bachman's Sparrow **(F)** Annual **(IQ)** Currently unknown- based on accuracy and reliability of forest **(Sc)** Forest	Restore habitat

		(Sc) Southeastern US **(A)** Significant decrease in populations or shift in range away from FMNF		**(A)** Significant decrease in Bachman's Sparrow populations	

System driver – Carbon Sequestration

Focal Resource	Stressor	Broad Scale Measures; Indicators	Management Unit Measures; Indicators	Current Forest Monitoring	Possibilities for Change
Loblolly Pine	Clear-cut loblolly stands on nutrient-poor sandy soils remained a carbon source for 6 years after clear-cutting, whereas fertilized stands became sinks within 6 years. Leaf-area index also increased much faster in the fertilized stands (Hyvonen et al., 2007). Loblolly pine plantations in a study in the coastal plain of North Carolina sequestered 360–835 gCm^2 per year (Noormets et al., 2010).	No monitoring needed, but potential sources are FIA and RMRS	No monitoring needed	No monitoring needed	If there is a need for high carbon sequestration, fertilize clearcut loblolly stands accordingly before regeneration.

System driver – Stand Composition and Outbreak History

Focal Resource	Stressor	Broad Scale Measures; Indicators	Management Unit Measures; Indicators	Current Forest Monitoring	Possibilities for Change
SPB	Greater proportions of host species and increased competition in stands increase the chance of SPB outbreak (Billings et al., 1985; Duehl et al., 2011; Gumpertz et al., 2000; Lombardero et al., 2000b). Outbreak levels from one year are positively correlated with those of the following year (Duehl et al., 2011).	Predicted and Observed Infestations **(S)** FHTET Forest Pest Conditions and FHTET National Insect and Disease Risk Map **(F)** Annual **(IQ)** Accuracy – collected from aerial surveys, ground surveys, and remote	Outbreak Levels **(S)** Santee Experimental Forest **(F)** Annual **(IQ)** **(Sc)** Forest and regional **(A)** Infestations above endemic levels	SPB Infestations **(S)** Location and population trends of SPB infestations **(F)** Annual **(IQ)** Currently unknown-based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant increase	Shift away from planting host species, especially after mortality from a high infestation year; take extra measures to protect against infestation after a high infestation year

		sensing; reliability – updated annually and as events occur; relevance – data available on many scales **(Sc)** Forest and regional **(A)** Infestations above endemic levels, or projected increase in infestations		in infestations	

System driver – Sea Level Rise and Flooding

Focal Resource	**Stressor**	**Broad Scale Measures; Indicators**	**Management Unit Measures; Indicators**	**Current Forest Monitoring**	**Possibilities for Change**
Baldcypress	Basal area increment suffered on frequently flooded swamps in South Carolina, meaning productivity may be best on sites experiencing less frequent tidal floods. Along tidal rivers, frequent flooding decreased growth, but increased flood durations and associated longterm ponding increased growth (Krauss et al., 2009). Flooding could impact seed dispersal and regeneration, but the direction and magnitude are uncertain for FMNF, as no studies have been done in South Carolina (Middleton, 2009).	Sea Level Rise **(S)** NOAA Tides and Currents **(F)** Every 3-5 years **(IQ)** Accuracy – accurate within a scientifically appropriate degree of imprecision or error; reliability – real-time; relevance – on the forest **(Sc)** Springmaid Pier and Charleston gauges **(A)** Rise in sea level such that tidal flooding in the baldcypress forests has increased	Tidal Flooding **(S)** Baruch Institute **(F)** Annually **(IQ)** **(Sc)** Coastal baldcypress stands **(A)** Increased flooding Baldcypress Growth **(S)** Santee Experimental Forest **(F)** Every 3-5 years **(IQ)** **(Sc)** Coastal baldcypress stands **(A)** Reduced growth Regeneration **(S)** Santee Experimental Forest **(F)** Every 3-5 years **(IQ)** **(Sc)** Coastal baldcypress stands	Not currently in forest monitoring plan	Favor baldcypress on sites prone to experiencing longer but less frequent floods. If applicable, restore or create hydrology that favors longer flood duration and ponding, as opposed to frequent flooding.

			(A) Declining regeneration rates		

System driver - Increased CO_2

Focal Resource	Stressor	Broad Scale Measures; Indicators	Management Unit Measures; Indicators	Current Forest Monitoring	Possibilities for Change
Loblolly Pine	Loblolly seedlings grown under elevated CO_2 scenarios were less likely to die after infection from the fusiform rust fungus (*Cronartium quercuum* f. sp. fusoforme) and pitch canker (*Fusarium cincinatum*). Rates of infection, however, were not significantly different. The seedlings also grew taller under elevated CO_2 scenarios (Runion et al., 2010). Elevated CO_2 has led to and is predicted to lead to increases in wood growth of loblolly pine. Increases were between 11-13% in a warm and cool site, respectively, in Georgia (Galik & Jackson, 2009; Wertin et al., 2012b), other studies say that if there is any increase in growth, it will likely be small (Huang et al., 2011). Elevated CO_2 increases basal area growth and productivity for at least 6 years, but lack of corresponding nitrogen mineralization could reduce this growth in the longer term. Growth is greater for emergent and dominant trees than subcanopy or suppressed trees, which may suffer a competitive disadvantage in an elevated CO_2 scenario (Moore et al., 2006).	No monitoring needed	No monitoring needed	No monitoring needed	
NNIS	Some invasive species are able to gain a competitive advantage from the increased CO_2 concentrations in the atmosphere, for example, allowing them to spend more	Atmospheric CO_2 Concentrations **(S)** NOAA Earth Systems Research Laboratory	NNIS **(S)** Baruch Institute **(F)** Annual **(IQ)**	NNIS **(S)** Invasive species abundance **(F)** Annual	Take extra measures to control NNIS

	carbon on root biomass. This process could decrease the effectiveness of herbicides. C3 species are more likely to respond with faster growth to increased CO2 concentrations, while C4 species will respond to increased temperatures (Joyce et al., 2008).	**(F)** Every 3-5 years **(IQ)** Accuracy – not guaranteed; reliability – not guaranteed; relevance - global **(Sc)** Global **(A)** Significant increase in CO2 concentrations Invasive Species Range **(S)** EDDMaps **(F)** Every 3-5 years **(IQ)** Accuracy – data can be collected by most, but requires specific information such as GPS location, data rated according to extent of documentation from collector; relevance - regionally and locally specific **(Sc)** Southeastern United States **(A)** Significant increase in invasive species trends	**(Sc)** Forest **(A)** Significant increases in NNIS abundance	**(IQ)** Currently unknown- based on accuracy and reliability of forest **(Sc)** Forest **(A)** Significant increase in NNIS abundance	

System driver - Disturbance Events

Focal Resource	Stressor	Broad Scale Measures; Indicators	Management Unit Measures; Indicators	Current Forest Monitoring	Possibilities for Change
Bachman's Sparrow	Hurricane disturbances can improve habitat for Bachman's Sparrow (Brooks & Stouffer, 2010).	No monitoring needed	No monitoring needed	No monitoring needed	
Swainson's Warbler	Swainson's Warbler has reacted positively to hurricane disturbances, due to improved habitat suitability (Brown et al.,	No monitoring needed	No monitoring needed	No monitoring needed	

	2011).				
NNIS	Disturbance events can provide opportunities for invasive species to flourish. Floods, in particular, can disperse invasive species (Joyce et al., 2008).	High Winds **(S)** NOAA Extreme Winds **(F)** Annual (monthly extremes) **(IQ)** Accuracy – accurate within a scientifically appropriate degree of imprecision or error; reliability – real-time; relevance – on the forest **(Sc)** Carolinas coastal region **(A)** A significant increase in frequency or severity of high wind events Stream Water Levels **(S)** USGS Water Alerts **(F)** Every 3-5 years (compare with historical) **(IQ)** Accuracy – provisional data may be inaccurate but is reviewed; reliability – real-time; relevance – on the forest **(Sc)** Watershed (8 digit HUC) **(A)** Increasing trend in floods and high water events	Windthrow **(S)** Santee Experimental Forest/CISA/Baruch Institute **(F)** Annually, but only in years where major wind events have occurred **(Sc)** Stand **(A)** Increasing instances of windthrow Stream Water Levels **(S)** SEF **(F)** Annually **(IQ)** Accuracy - observed and well documented; reliability – well documented including periods of missing data; relevance – on the forest **(Sc)** Forest **(A)** Increasing trend in floods and high water events	NNIS **(S)** Invasive species abundance **(F)** Annual **(IQ)** Currently unknown- based on accuracy and reliability of forest **(Sc)** Forest (can focus on post-disturbance areas) **(A)** Significant increase in NNIS abundance	Take extra measures to control NNIS

Focal Species

System Driver – Natural Succession

Focal Resource	**Stressor**	**Broad Scale Measures; Indicators**	**Management Unit Measures; Indicators**	**Current Forest Monitoring**	**Possibilities for Change**
Northern bobwhite Quail (*Colinus virginianus*)	Natural succession reduces habitat availability and suitability for northern bobwhite quail.	<u>Population Levels</u> **(S)** North American Breeding Bird Survey **(F)** Annual **(Sc)** South Carolina **(IQ)** Accuracy –no guarantee of accuracy, not all of the data on the website meets criteria for inclusion in annual BBS analysis (Run Type 1 data does) **(A)** Significant decrease in bobwhite counts <u>Habitat Distribution</u> **(S)** Climate Change Bird Atlas **(F)** Annual **(Sc)** South Carolina **(IQ)** Accuracy - high model reliability **(A)** Significant decrease in bobwhite counts	<u>Hunter Success</u> **(S)** SCDNR **(F)** Annual **(Sc)** State – Northern Coastal Plain; Southern Coastal Plain; Midlands; and Piedmont **(IQ)** Accuracy – uses Breeding Bird Survey data (see previous column) and call count data **(A)** Significant decrease in bobwhite counts <u>Habitat Suitability</u> **(S)** Quail Forever (Q) **(F)** Annual **(Sc)** Forest **(IQ)** Accuracy – currently unknown; will follow up with source **(A)** Habitat Suitability has declined	<u>Bobwhite Population</u> **(S)** Quail call counts **(F)** Annual **(Sc)** Forest **(IQ)** Accuracy and reliability – quail call counts taken from four routes within FMNF **(A)** Significant decrease in bobwhite counts <u>Prescribed Burning</u> **(S)** Burning records **(F)** Annual **(Sc)** Forest **(IQ)** Accuracy based on data input into records **(A)** Significant decrease in acres burned	Increase the amount of thinnings conducted on the FMNF and implement ecological restoration, especially longleaf pine restoration. Pine thinnings should try to reduce densely stocked pine stands to a residual basal area of 50-60 square feet per acre or less. Prescribed burning on more frequent intervals and in such a way as to burn in a mosaic pattern.

Recreation

System Driver – Human Disturbance

Focal Resource	Stressor	Broad Scale Measures; Indicators	Management Unit Measures; Indicators	Current Forest Monitoring	Possibilities for Change
Recreation	Increased human traffic from recreation, as well as population increases and consequent urban and suburban expansion, can negatively impact the forest's resources**.**	Population Levels **(S)** Census data **(F)** Every 3-5 years **(Sc)** Berkeley and Charleston counties **(IQ)** Accuracy - unknown based on sampling techniques **(A)** Significant increase in population	Housing Developments **(S)** County data **(F)** Every 3-5 years **(Sc)** Berkeley and Charleston Counties (IQ) Accuracy – unknown based on court house records **(A)** Significant increase in proposed or built housing developments; housing developments shifting towards the forest	Visitor use **(S)** Visitation data from NVUM Report **(F)** 5 years **(Sc)** Forest **(IQ)** Accuracy and reliability – unknown based on sampling techniques **(A)** Significant increase in visitation	Improve buffers on edge of forest; if appropriate, control visitor access to sensitive parts of the forest (i.e. trail development in the Wando area)

Other: focal resources identified in TACCIMO, but unclear if relevant to FMNF

- Sea level rise threatens nesting waterbirds such as laughing gulls (Leucophaes atricilla), clapper rails (Rallus longirostris), and Forster's terns (Sterna forsteri) (Erwin et al., 2006)
- Hurricanes threaten the endangered black-capped petrel (Pterodroma hasitata) north of Florida (Hass et al., 2012)
- Habitats for Acadian fly catcher (*Empidonax virescens*), Yellow-throated Vireo (*Vireo flavifrons*), Northern Parula (*Parunla americana*), and Summer Tanager (*Piranga rubra*) are expected to decline on the Georgia coast as sea level rises (Brittain & Craft, 2012)
- Wood Stork (*Mycteria americana*) breeding success is impacted by rainfall, with high rains during breeding season having a negative impact (Bryan & Robinette, 2008). The Wood Stork's tidal forest habitat is also threatened by sea level rise, unless those wetlands can migrate upriver (Craft, 2012).
- Neo-tropical migratory bird habitat in tidal forests is threatened by sea level rise, unless those wetlands can migrate upriver (Craft, 2012).

Abbreviations

ACE – Army Corps of Engineers

CISA – Carolinas Integrated Sciences and Assessments

FIA – Forest Inventory Analysis

NIDIS – National Integrated Drought Information System

NOAA – National Oceanic and Atmospheric Administration

USGS – United States Geological Survey

Citations for Information Quality

Santee Experimental Forest Climate Data

http://cybergis.uncc.edu/santee/TurkeyCr_halfhourly_data_2005_2011.html#Data_Quality_Information

CISA Dynamic Drought Index Tool

http://www.cisa.sc.edu/DDIT.html

EDDMaps

http://www.eddmaps.org/about/appropriate_data.html

FIA

http://www.fia.fs.fed.us/library/database-documentation/current/ver6.0/FIADB_user%20guide_6-0_p2_5-6-2014.pdf

National Visitor Use Monitoring

http://www.fs.fed.us/nrm/nvum/results/WebHelp/#Single_Forest_Tab.htm

NIDIS Current Data

http://www.drought.gov/drought/content/site-disclaimers

NIDIS Historical Data

http://droughtatlas.unl.edu/Methodology/StationCriteria.aspx

NOAA

http://www.cio.noaa.gov/services_programs/info_quality.html

North American Breeding Bird Survey

https://www.pwrc.usgs.gov/bbs/RawData/FTPdisclaim.cfm

SCDNR Northern Bobwhite

http://www.dnr.sc.gov/cwcs/pdf/Northernbobwhite.pdf

USGS Water Alerts

http://water.usgs.gov/wateralert/provisional.html

References

Bhuta, A. A., Kennedy, L. M., & Pederson, N. (2009). Climate-radial growth relationships of northern latitudinal range margin longleaf pine (Pinus palustris P. Mill.) in the Atlantic coastal plain of southeastern Virginia. *Tree-Ring Research*, *65*(2), 105-115.

Billings, R.F., Bryant, C.M., Wilson, K.H., 1985. Development, Implementation, and Validation of a Large Area Hazard- and Risk-rating System for the Southern Pine Beetle. USDA Forest Service, Southern Research Station General Technical Report SO-56, NC, USA, pp. 226–232.

Brooks, M. E., & Stouffer, P. C. (2010). Effects of Hurricane Katrina and Salvage Logging on Bachman's Sparrow. The Condor, 112(4), 744-753. doi:10.1525/cond.2010.100019

Brown, D. R., Sherry, T. W., & Harris, J. (2011). Hurricane Katrina impacts the breeding bird community in a bottomland hardwood forest of the Pearl River basin, Louisiana. Forest ecology and management, 261(1), 111-119.

Carpenter, S. R., Fisher, S. G., Grimm, N. B., & Kitchell, J. F. (1992). Global change and freshwater ecosytems. Annual Review Ecological Systems, 119-139.

Conner, R. N., Saenz, D., Schaefer, R. R., McCormick, J. R., Rudolph, D. C., & Burt, B. (2005). Rainfall, El Nino, and Reproduction of Red-cockaded Woodpeckers. Southeastern Naturalist, 4(2), 347-354.

Coutant, C. C. (1990). Temperature-Oxygen habitat for freshwater and coastal striped bass in a changing climate. Transactions of the American Fisheries Society, 119(2), 240-253. doi:10.1577/1548-8659(1990).

Czwartacki, B.J. 2013. Time and tide: Understanding the water dynamics in a tidal freshwater forested wetland. M.S. Thesis, Environmental Studies Program, College of Charleston. 129 pg.

Dale, V. H., Lannom, K. O., Tharp, M. L., Hodges, D. G., & Fogel, J. (2009). Effects of climate change, land-use change, and invasive species on the ecology of the Cumberland forests. Canadian Journal of Forest Research, 39, 467-480. doi:10.1139/X08-172

Daniels, R. C., White, T. W., & Chapman, K. K. (1993). Sea-level rise: destruc�on of threatened and endangered species habitat in South Carolina. Environmental Management, 17(3), 373-385. doi:10.1007/bf02394680.

Day, J. W., Christian, R. R., Boesch, D. M., Y6caz-Arancibia, A., Morris, J., Twilley, R. R., … & Stevenson, C. (2008). Consequences of Climate Change on the Ecogeomorphology of Coastal Wetlands. Estuaries and Coasts, 31, 477-491. doi: 10.1007/s12237-008-9047-

Drake, J. M., & Bossenbroek, J. M. (2004). The potential distribution of zebra mussels in the United States. BioScience, 54(10), 931-941. doi:10.1641/00063568(2004)054[0931:TPDOZM]2.0.CO;2

Duehl, A. J., Koch, F. H., & Hain, F. P. (2011). Southern pine beetle regional outbreaks modeled on landscape, climate and infestation history. Forest Ecology and Management, 261(3), 473-479. doi:10.1016/j.foreco.2010.10.032.

Fang, X., Stefan, H. G., Eaton, J., G., McCormick, J. H., & Alam, S. R. (2004). Simulation of thermal/dissolved oxygen habitat for fishes in lakes under different climate scenarios Part 1. Cool-water fish in the contiguous US. Ecological Modelling, 172, 13-

Galik, C. S. & Jackson, R. B. (2009). Risks to forest carbon offset projects in a changing climate. Forest Ecology and Management, 257(11), 2209-2216. doi:10.1016/j.foreco.2009.03.017

Gan, J. (2004). Risk and damage of southern pine beetle outbreaks under global climate change. *Forest Ecology and Management*, *191*(1), 61-71.

Gedan, K. B., Altieri, A. H., & Bertness, M. D. (2011). Uncertain future of New England salt marshes. Marine Ecology Progress Series. 434. 229-237. doi: 10.3354/meps09084

Golladay, S. W., Gagnon, P., Kearns, M., Battle, J. M., & Hicks, D. W. (2004). Response of freshwater mussel assemblages (Bivalvia: Unionidae) to a record drought in the Gulf Coastal Plain of southwestern Georgia. Freshwater Science, 23(3), 494-506. doi: 10.1899/0887-3593(2004)023<0494:ROFMAB>2.0.CO;2

Guha, H. & Panday, S. (2012). Impact of sea level rise on groundwater salinity in a coastal community of South Florida. Journal of the American Water Resources Association, 1-19. doi:10.1111/j.1752-1688.2011.00630.x

Gumpertz, M.L., Wu, C-t., Pye, J.M., 2000. Logistic regression for southern pine beetle outbreaks with spatial and temporal autocorrelation. For. Sci. 46, 95–107

Heilman, W. E., Potter, B. E., & Zerbe, J. I. (1998). Regional climate change in the southern united states: The implications for wildfire occurrence. Productivity & Sustainability of Southern Forest Ecosystems in a Changing Environment, 1, 683-699.

Huang, J., Abt, B., Kinderman, G., Ghosh, S. (2011). Empirical analysis of climate change impact on loblolly pine plantations in the southern United States. Natural Resource Modeling, 24(4), 445-476. doi: 10.1111/j.1939-7445.2011.00098.x

Hyvonen, R., Agren, G. I., Linder, S., Persson, T., Cotrufo, M. F., Ekblad, A., . . . Wallin, G. (2007). Thelikely impact of elevated [co2], nitrogen deposition, increased temperature and management on carbon sequestration in temperate and boreal forest ecosystems: A literature review. New Phytologist, 173, 462-480.

Iverson, L. R., & Prasad, A. M. (2001). Potential changes in tree species richness and forest community types following climate change. *Ecosystems*,*4*(3), 186-199.

Iverson, L. R., & Prasad, A. M. (2001). Potential redistribution of tree species habitat under five climate change scenarios in the Eastern U.S. Forest Ecology and Management, 155, 205-222.

Jayakaran, A.D., T.M. Williams, H. Ssegane, D.M. Amatya, B. Song, C.C. Trettin. 2014. Hurricane impacts on a pair of coastal forested watersheds: implications of selective hurricane damage to forest structure and streamflow dyanmics. Hydrol. Earth Syst. Sci. 18:1151-1164.

Johnsen, K. H., Butnor, J. R., Kush, J. S., Schmidtling, R. C., & Nelson, C. D. (2009). Hurricane Katrina winds damaged longleaf pine less than loblolly pine.*Southern journal of applied forestry*, *33*(4), 178-181.

Joyce, L. A., Blate, G. M., Littell, J. S., McNulty, S. G., Millar, C. I., Moser, S. C., . . . Peterson, D. L. (2008). National forests. in: Preliminary review of adaptation options for climate-sensitive ecosystems and resources. a report by the U.S. climate change science program and the subcommittee on global change research. U.S.Environmental Protection Agency, 1-127.

Liu, Y., Goodrick, S. L., & Stanturf J. A. (2012). Future U.S. wildfire potential trends projected using a dynamically downscaled climate change scenario. Forest Ecology and Management, In press. doi:10.1016/j.foreco.2012.06.049

Loehman, R. A., Reinhardt, E. & Riley, K. L. (2014). Wildland fire emissions, carbon, and climate: Seeing the forest and the trees – A cross-scale assessment of wildfire and carbon dynamics in fire-prone, forested ecosystems. Forest Ecology and Management, 317, 9 – 19. http://dx.doi.org/10.1016/j.foreco.2013.04.014

Lombardero, M.J., Ayres, M.P., Lorio Jr., P.L., Ruel, J.J., 2000b. Environmental effects on constitutive and inducible resin defences of Pinus taeda. Ecol. Lett. 3, 329–339.

McNulty, S. G. (2002). Hurricane impacts on us forest carbon sequestration. Environmental Pollution, 116, 817-824. doi:10.1016/S0269-7491(01)00242-1.

McNulty, S. G., & Boggs, J. L. (2010). A conceptual framework: Redefining forest soil's critical acid loads under a changing climate. Environmental Pollution, 2053-2058.

Meyer, J. L., Sale, M. J., Mulholland, P. J., & Poff, N. L. (1999). Impacts of climate change on aquatic ecosystem functioning and health. Journal of the American Water Resources Association, 1373-1386.

Mitchener, L. J., & Parker, A. J. (2005). Climate, lightning, and wildfire in the national forests of the southeastern United States: 1989-1998. Physical Geography, 26(2), 147-162.

Moore, D. J., Aref, S., Ho, R. M., Pippen, J. S., Hamilton, J. G., & DeLucia, E. H. (2006). Annual basal area increment and growth duration of Pinus taeda in response to eight years of free-air carbon dioxide enrichment. Global Change Biology, 12, 1367–1377. doi: 10.1111/j.1365-2486.2006.01189.x

Mohseni, O., Stefan, H. G., & Eaton, J. G. (2003). Global warming and potential changes in fish habitat in U.S. streams. Climatic Change, 59, 389-409.

Mulholland, P. J., Best, G. R., Coutant, C. C., Hornberger, G. M., Meyer, J. L., Robinson, P. J, Stenberg, J. R., … & Wetzel, R. G. (1997). Effects of climate change on freshwater ecosystems of the south-eastern United States and the Gulf Coast of Mexico. Hydrological Processes, 11, 949-970. doi: 10.1002/(SICI)1099-1085(19970630)11:8<949::AID-HYP513>3.0.CO;2-G.

Nedlo, J. E., Martin, T. A., Vose, J. M., & Teskey, R. O. (2009). Growing season temperatures limit growth of loblolly pine (Pinus taeda L.) seedlings across a wide geographic transect. Trees, 23, 751-759. doi: 10.1007/s00468-009-0317-0

Noormets, A., Gavazzi, M. J., McNulty, S. G., Domec, J.-C., Sun, G., King, J. S., & Chen, J. (2010). Response of carbon fluxes to drought in a coastal plain loblolly pine forest. Global Change Biology, 16 (1), 272-287. doi:10.1111/j.1365-2486.2009.01928.x

Noyes, P. D., McElwee, M. K., Miller, H. D., Clark, B. W., Van Tiem, L. A., Walcott, K. C., … & Levin, E. D. (2009). The toxicology of climate change: Environmental contaminants in a warming world. Environment International, 35(6), 971-986.

Olden, J. D., Kennard, M. J., Lawler, J. J., & Poff, N. L. (2011). Challenges and opportunities in implementing managed relocations for conservation of freshwater species. Conservation Biology, 25(1), 40-47.

Poulter, B., Christensen, N. L., and Qian, S. S. (2008). Tolerance of pinus taeda and pinus serotina to low salinity and flooding: Implications for equilibrium vegetation dynamics. Journal of Vegetation Science, 19(1), 15-22. doi:10.3170/2007-8-18410.

Rahel, F. J., & Olden, J. D. (2008). Assessing the Effects of Climate Change on Aquatic Invasive Species. Conservation Biology, 22(3), 521–533. doi: 10.1111/j.1523- 1739.2008.00950.x.

Rotzoll, K. & Fletcher, C. H. (2012). Assessment of groundwater inundation as a consequence of sea-level rise. Nature Climate Change, online first, 1758-6798. doi:10.1038/nclimate1725

Runion, G. B., Prior, S. A., Rogers, H. H., & Mitchell, R. J. (2010). Effects of elevated atmospheric CO2 on two southern forest diseases. New Forests, 39, 275-285. doi: 10.1007/s11056-009-9170-7

Samuelson, L. J., Stokes, T. A., & Johnsen, K. H. (2012). Ecophysiological comparison of 50-year-old longleaf pine, slash pine and loblolly pine. *Forest Ecology and Management*, *274*, 108-115.

Schiegg, K., Pasinelli, G., Walters, J. R., & Daniels, S. J. (2002). Inbreeding and experience affect response to climate change by endangered woodpeckers. Proceedings of the Royal Society of London. Series B: Biological Sciences, 269(1496), 1153-1159. doi:10.1098/rspb.2002.1966.

Sharma, S., Jackson, D. A., Minns, C. K., & Shuter, B. J. (2007). Will northern fish populations be in hot water because of climate change? Global Change Biology, 13, 2052 – 2064.

Spooner, D. E., & Vaughn, C. C. (2008). A trait-based approach to species' roles in stream ecosystems: climate change, community structure, and material cycling. Oecologia, 158(2), 307-317. doi: 10.1007/s00442-008-1132-9.

Spooner, D. E., Xenopoulos, M. A., Schneider, C., and Woolnough, D. A. (2011). Coextirpation of host–affiliate relationships in rivers: the role of climate change, water withdrawal, and host-specificity. Global Change Biology, 17(4), 1720-1732. doi:10.1111/j.1365-2486.2010.02372.x

Stefan, H. G., Fang, X. & Eaton, J. G. (2001). Simulated fish habitat changes in North American lakes in response to projected climate warming. Transactions of the American Fisheries Society, 130, 459 – 477.

Xenopoulos, M. A., & Lodge, D. M. (2006). Going with the flow: using species-discharge relationships to forecast losses in fish biodiversity. Ecology, 87(8), 1907-1914. doi:10.1890/0012-9658(2006)87[1907:GWTFUS]2.0.CO;2

Warner, N. N. & Tissot, P. E. (2012). Storm flooding sensitivity to sea level rise for Galveston Bay, Texas. Ocean Engineering, 44, 23-32.

Weed, A. S., Ayres, M. P. & Hicke, J. A. (2013). Consequences of climate change for biotic disturbances in North American forests. Ecological Monographs, 83 (4), 441 – 470.

Wertin, T. M., McGuire, M. A., & Teskey, R. O. (2012a). Effects of predicted future and current atmospheric temperature and [CO2] and high and low soil moisture on gas exchange and growth of Pinus taeda seedlings at cool and warm sites in the species range. Tree Physiology, 32(7), 847-858. doi:10.1093/treephys/tps051

Williams, D. W., & Liebhold, A. M. (2002). Climate change and the outbreak ranges of two North American bark beetles. Agricultural and Forest Entomology, 4, 87-99.